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ABSTRACT

This study investigated the effects of two levels of spatial ability--high spatial, low spatial--and two different presentation platforms--virtual reality, computer monitor--on performance of a pictured rotation task over two consecutive trials. Performance was measured by response time and accuracy. The 24 male and 8 female subjects (college freshmen in a Reserve Officer Training Course) were blocked by spatial ability and performed the pictured rotation task on both the virtual reality and the computer monitor platforms. The order of the presentation platforms was counterbalanced across subjects. Results indicate that subjects with high spatial ability responded significantly faster and were more accurate on the rotation task than those with low spatial ability. There was a significant difference in accuracy for the virtual reality platform over the computer monitor platform. Both spatial ability groups also had significant decreases in response times on the second trial. The findings relate directly to the design of instructional platforms as well as future studies on spatial ability differences. (Contains 1 illustration, 2 tables, 3 figures, and 10 references.) (Author/SLD)

Effects of Spatial Ability Levels and Presentation Platform on Performance of a Pictured Rotation Task

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Abstract

This study investigated the effects of two levels of spatial ability--high spatial, low spatial—and two different presentation platforms—virtual reality, computer monitor—on performance of a pictured rotation task over two consecutive trials. Performance was measured by response time and accuracy. Subjects were blocked by spatial ability and performed the pictured rotation task on both the virtual reality and the computer monitor platforms. The order of the presentation platforms was counterbalanced across subjects. Results indicated that subjects with high spatial ability responded significantly faster and were more accurate on the rotation task than those with low spatial ability. There was a significant difference in accuracy for the virtual reality platform over the computer monitor platform. Both spatial ability groups also had significant decreases in response times on the second trial. The findings relate directly to the design of instructional platforms as well as future studies on spatial ability differences.

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Introduction

Considerable research has been devoted to the subject of individual differences in spatial ability. Researchers have looked at many variables to try and explain how these differences occur between individuals. Whether it's left or right handedness, gender, video game experience, or a few others, most of these studies have included some measure of our ability to mentally rotate objects in space (Shepherd & Metzler, 1971, Guay, 1976).

Reviews of recent studies suggest that these spatial abilities are not fixed but can be manipulated through practice(Subrahman & Greenfield, 1994). This would imply that there might not be any inherent differences in levels of spatial skills of individuals. Some have even found that lower spatial ability subjects have benefited more after practice than higher spatial ability subjects. (Subrahman & Greenfield, 1994).

If spatial skill is strongly affected by practice, as evidenced by its response to practice such as computer video game exposure (Okagashi & Frensch, 1994), then the findings of differences between genders becomes less important. We should be concentrating more on ways in which to train for these skills than in finding new ways in which to separate by them.

Because of the nature of most current measures of spatial skills, a large number of studies have been conducted utilizing the computer as the display platform (Shah & Miyake, 1996, Greenfield et al, 1994). This is due to the computer being so well suited in generating the type of graphics required to create the rotation in space images of most spatial tasks. However, not much research has been conducted on differences between computer platforms, especially for different forms of visual presentations.

Some researchers have begun to work with synthetic or "virtual" environments (Calvert & Lan Tan, 1994; McCormick & Wickens, 1995) and have found interesting properties associated with them. Calvert & Lan Tan (1995) found distinct physiological differences in subjects participating in virtual reality games simulating dangerous situations, including increased heart rates and perspiration for participants over observers of virtual reality games. The McCormick study (1995) showed some inconclusive results on the benefits of virtual immersion, with it benefiting performance on some tasks but hurting it on others.

It might be possible that the characteristic feeling of total immersion, typical of virtual environments, might have a psychological effect in participants that might result in heightened levels of alertness. This heightened alertness should manifest itself in increased performance levels in certain virtual settings.

Another question that remains unanswered is whether or not lower spatial ability subjects actually react differently to practice than do higher spatial ability subjects (Subrahman & Greenfield, 1994). If that is the case, this difference may manifest itself in the form of larger practice effects for lower spatial ability subjects than those experienced by higher spatial ability subjects.

The primary purpose of this study was to investigate the effects of two levels of spatial ability—high, low—on performance of a pictured rotation task across two different platforms—virtual reality, computer monitor-- measured over two consecutive trials involving multiple practice items. Data were also collected on attitudes towards the performance task.

It was hypothesized that high spatial ability subjects would outperform lower spatial ability subjects on both presentation platforms. It was expected, however, that lower spatial ability subjects would benefit more from practice effects by demonstrating faster response time changes on the second trial than the higher spatial ability subjects. It was also theorized that the lower spatial ability subjects might benefit more from the sense of immersion of the virtual platform and perform better on it than on the computer monitor.

There were three dependent measures in this study. Response time was measured in seconds from the time a frame was viewed until a determination of same or different was made and was reported as seconds per frame. Accuracy was measured as a proportion of correct answers to number of frames viewed. It was reported as percent correct. The final dependent measure was attitude, as recorded by each subject on an end of experiment questionnaire.

METHOD

Subjects

Subjects were college freshmen from the Reserve Officer Training Course (ROTC) program at Arizona State University. They were all first year participants in the ROTC program. Fifty two were pre-tested and a final group of twenty four males and eight females were selected to participate.

Even though this was an Air Force ROTC program, not all students were prospective pilots and therefore spatial skills were quite varied. These students, however, tended to be more studious than the general college population due to program requirements that establish minimum grade point averages to remain affiliated with ROTC. Most of them had considerable access to computers and had had some instruction delivered via that medium.

Procedures

After taking a spatial skills pre-test, those selected to participate were scheduled individually to return on another date to do the pictured rotation task. The day of the rotation task, they were given a brief set of instructions with accompanying pictured examples of what the rotation task entailed. Then they were all given a two minute familiarization demonstration on both the virtual reality and the computer monitor platforms. This demonstration included use of the response device (mouse) and use of the pause function. Following the demonstrations, each subject completed his/her first trial in the assigned platform followed by a fifteen minute break period. After the break period, the subject completed the rotation task on the other platform.

The spatial skills pre-test measure used was Vandenberg's Test of 3-D Spatial Visualization (Peters et al, 1995). Subjects whose raw score was in the top third of the total distribution of pre-test scores were placed in the "high" group, and those scoring in the bottom third of the distribution of scores were placed in the "low" group.
Those scoring in the middle third of the distribution did not participate in the rotation task. This resulted in a total of 16 subjects in each of the two groups—high spatial and low spatial.

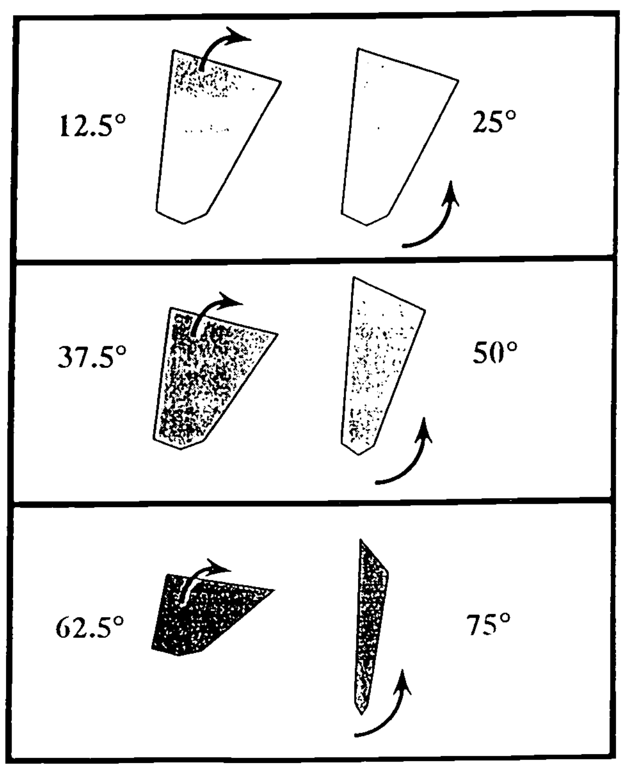
The treatments—virtual reality, computer monitor—differed only by the presentation platform used. The virtual reality platform consisted of a commercially available virtual reality helmet that displayed the rotation exercise on two miniature head mounted screens. The helmet had to be fitted individually, and had focus adjustments for each lens, as well as for head size. The computer monitor consisted of a large commercial computer monitor. Both platforms were controlled by the same computer "mouse", which was used to initiate the sequence, make selections, pause, and exit the task.

The rotation task involved making "same" or "different" determinations from pairs of rotating figures depicted in each of 192 frames. It was identical in both platforms except that the order in which the rotating figures appeared was random in each platform. Upon completion of each trial, the computer program randomly scrambled the order in which the figures appeared in the next trial.

Materials

The rotation task was composed of a series of paired flat geometric shapes that appeared at varying levels of rotation, from a low of 12.5 degrees of rotation in depth, to a high of 75 degrees rotation in depth. There were a total of six possible angles of rotation (12.5, 25, 37.5, 50, 62.5, 75). The figures were rotated both along the vertical and horizontal axis. They could be depicted as either both rotating or one rotating and the other one not. Rotations all occurred in depth and there was no rotation in the picture plane. Illustration one depicts typical figures and possible angles of rotation:

Illustration 1 Typical figures and possible angles of rotation



The task for the subjects was to make a determination of whether the two figures depicted in each screen were the same or whether they were different. Half the total screens depicted "same" figures in different angles of rotation and the other half depicted dissimilar or "different" shapes in different angles of rotation. There were a total of 192 screens per each trial with an equivalent number of same and different pairings (96 each). Each of the six angles of rotation was depicted 32 times, with 16 "same" and 16 "different" pairs.

Subjects had to make a determination of "same" or "different" on every screen and indicate so prior to continuing to the next screen. Selection was made with a computer "mouse" with left click indicating "same" and right click indicating "different". The center mouse button would pause the program and stop the timer.

Criterion Measures

The three main criterion measures employed were response time, accuracy, and attitude. Response time was stated in seconds per frame, accuracy was stated as percent correct, and attitude was expressed as a number value on a Likert-type scale. Response time was measured from the time a screen was activated to the time a selection of same or different was made. The program had a default action that advanced to the next screen after 20 seconds without a response. Accuracy was measured as a percentage of error by dividing the number of errors (selecting same when it was different or different when it was same) by the total number of responses.

Attitudes towards the task were measured by having subjects complete an attitudinal survey upon completion of the pictured rotation task. The survey consisted of eight closed questions on a Likert scale ranging from 1 (strongly agree) to 4 (strongly disagree). There was one open ended question that asked for any factor that might have influenced their performance on the rotation task.

Design and Data Analysis

A 2X2X2 factorial design was used, with spatial ability level (high, low) presentation platform (virtual reality, computer monitor) and trial (one, two) as the independent variables. Presentation platform and trial were within subjects variables. The dependent variable of performance was measured quantitatively using both reaction time and accuracy.

Data were analyzed using a 2(spatial ability)x2(platform)x2(trial) multivariate analysis of variance (MANOVA) for each of the dependent variables(accuracy, response time). Spatial ability was a between subjects variable and platform and trial were within subjects variables. Attitude data was analyzed using an analysis of variance of the overall questionnaire means.

RESULTS

Table 1 shows accuracy (proportion correct) by spatial ability level (high, low), platform type (virtual reality, computer monitor), and trial (one, two). The mean overall accuracy rates were .804 for high spatial and .73 for low spatial. Mean overall accuracy by platform was .748 for virtual reality and .783 for computer monitor. Mean overall accuracy rates by trial were .762 for trial one and .77 for trial two.

Table 1 Pictured rotation task accuracy expressed as proportion correct

	Trial One		Trial Two		
	Virtual Reality	Computer Monitor	Virtual Reality	Computer Monitor	Total SD
High Sp	.758	.823	.826	.809	.804
SD	.107	.087	.091	.149	.11
Low Sp	.699	.769	.713	.731	.73
SD	.095	.069	.118	.118	.1
Total	.728	.796	.769	.77	.766
SD	.101	.078	.104	.133	.10

Overall means

High spatial = .804 accuracy	Virtual Reality =.748 accuracy	Trial One =.762 accuracy
Low spatial = .73 accuracy	Comp Monitor = .783 accuracy	Trial Two =.77 accuracy

Table 2 shows the mean response times (seconds per frame) by spatial ability level (high, low), platform type (virtual reality, computer monitor), and trial (one, two). The mean overall response times were 2.95 for high spatial and 3.95 for low spatial. Mean overall response times by platform were 3.39 for virtual reality and 3.53 for computer monitor. Mean overall response time by trial was 4.01 for trial one and 2.90 for trial two.

Table 2 Pictured rotation task response times expressed as seconds per frame

	Trial One		Trial Two		
	Virtual Reality	Computer Monitor	Virtual Reality	Computer Monitor	Total SD
High Sp	3.238	3.325	2.738	2.513	2.95
SD	.835	1.515	.986	1.091	1.10
Low Sp	4.638	4.863	2.913	3.438	3.95
SD	1.789	2.151	1.022	1.193	1.54
Total	3.94	4.09	2.83	2.98	3.45
SD	1.312	1.833	1.004	1.142	1.32

Overall means

High spatial = 2.95 seconds/frame Virtual Reality = 3.39 seconds/frame Trial One = 4.01 seconds/frame

Low spatial = 3.95 seconds/frame Comp Monitor = 3.53 seconds/frame Trial Two = 2.90 seconds/frame

Figure 1 shows the proportion of correct responses (accuracy) by angle of rotation for both spatial ability groups (high, low).

Figure 1 Accuracy by angle of rotation for both spatial ability groups

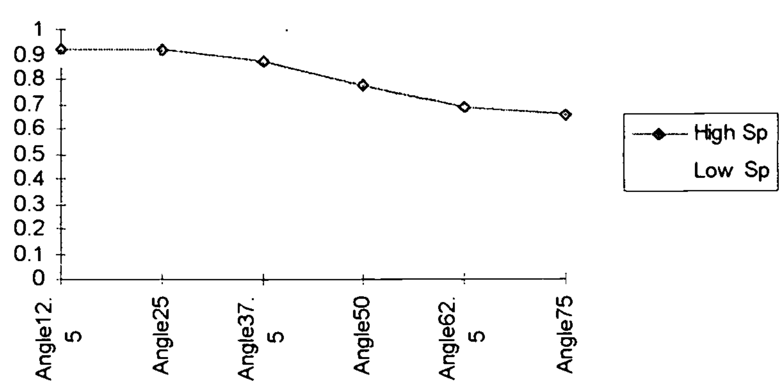


Figure two shows response time (seconds per frame) by angle of rotation for both spatial ability groups (high spatial, low spatial).

Figure 2 Response time by angle of rotation for both spatial ability groups

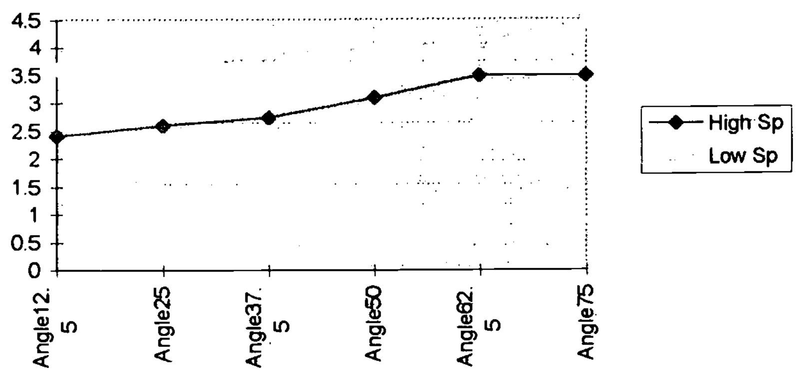
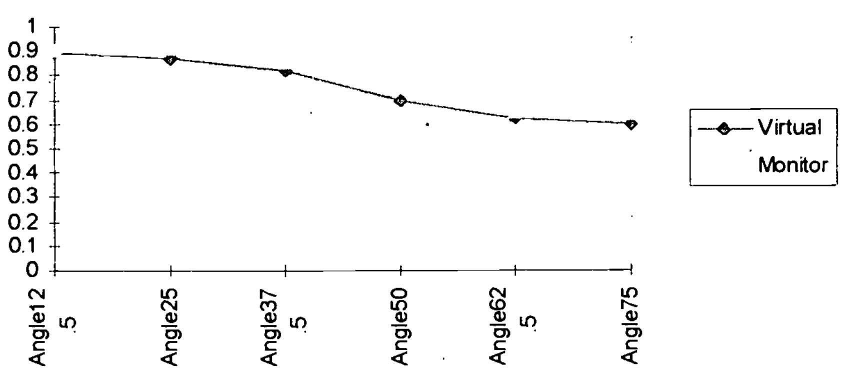


Figure 3 shows accuracy (proportion correct) by angle of rotation for both platforms (virtual reality, computer monitor).

Figure 3 Accuracy by angle of rotation for both platforms



The 2X2X2 MANOVA for accuracy revealed two significant differences for main effects variables. The mean overall accuracy of .804 for high spatial was significantly higher than the mean overall accuracy of .73 for low spatial, $F(1, 58) = 4.93$, $p = .034$. Also, the mean overall accuracy rate of .748 for virtual reality was significantly lower than the mean overall accuracy of .783 for computer monitor, $F(1, 58) = 5.49$, $p = .025$. There were no significant interactions.

The 2X2X2 MANOVA for response time revealed two other significant differences for main effects variables. The mean overall response time of 2.95 for high spatial was significantly lower than the 3.95 for low spatial, $F(1, 58) = 5.27$, $p = .028$. Also, the mean overall response time for trial one of 4.01 was significantly higher than the mean overall response time of 2.90 for trial two, $F(1, 58) = 8.979$, $p = .005$. This data did not reveal any significant interactions either.

The attitudinal questionnaire did not reveal any significant differences amongst the two groups. On question number five, when asked whether they preferred doing the rotation task on the Virtual Reality over the computer monitor, the mean response was 3.31 (1 indicating "strongly agree" and 4 indicating "strongly disagree"). Question number six stated "The VR was harder than the computer monitor". The mean response for #6 was 1.46 (1 indicating "strongly agree" and 4 indicating "strongly disagree").

DISCUSSION

The primary purpose of this study was to investigate the effects of two levels of spatial ability—high, low—on performance of a pictured rotation task across two different platforms—virtual reality, computer monitor-- measured over two consecutive trials. The results revealed that subjects with high spatial ability had significantly higher accuracy rates and significantly faster response times than those of lower spatial ability. They also indicate that subjects performing the rotation task on the computer monitor platform were significantly more accurate than when performing on the virtual reality platform. Furthermore, overall decreases in response time from trial one to trial two were highly significant.

The finding of significant differences among the two spatial ability levels validated our mental rotation task. It was theorized that if the spatial skills pretest measure (Vandenberg's Test of 3-D Spatial Visualization) was accurate in determining differences in mental rotation skills of three dimensional objects, then it might also predict performance in a rotation exercise of two dimensional objects. Since the objects in this study were two dimensional shapes depicted in varying angles of rotation, this would imply that it is not the 3-D aspects of the object, but the level of compression of that object that affects a person's ability to accomplish the mental rotation of the object and its subsequent identification. (Niall, in press)

The differences by spatial ability were further analyzed for each angle of rotation depicted in the experiment (12.5 through 75) for both accuracy and response times and were found to be equally significant across all angles. This seems to indicate that the performance difference was fairly robust and the high group was both faster and more accurate at all levels of rotation. It appears, then, that the high spatial performers are both faster and more accurate. In an earlier study by Birenbaum (1994) they had found that some subjects performed at a slower rate but were actually more accurate, due to a factor described as level of cautiousness. The lower spatial ability group in this study, however, is performing at both a slower level (higher response times) and is less accurate (lower proportion correct) than the higher spatial ability group.

The finding of a significant difference in accuracy for computer monitor (.783) over the virtual reality (.748) is interesting. One plausible cause for the accuracy difference rests on the resolution capabilities of the commercially acquired virtual reality helmet used in the experiment versus that of the large monitor. Even though, as can be seen in figure 1, at the lower and higher angles the differences are smallest, it is possible that at the middle angles of rotation (25-50) the greater resolution and relative size of the images accounts for the accuracy difference.

Another possible explanation for the accuracy disparity could be a factor of scale. The image on the virtual screen appears smaller in size than the one on the large computer monitor. As was determined by Schreiber (1996) in his study on map recognition, the larger scale display was superior to the smaller scale due to the subject having more information or cues with which to make a decision. It is possible, then, that subjects are using a greater number of cues to differentiate on the middle angles but this is not as helpful at the smaller or greater angles.

Interestingly, though, these differences are not present in the response times. It seems that subjects are not affected by resolution or scale when making a decision of "same" or "different". Mean response time of 3.39 for virtual reality and 3.53 computer monitor were insignificantly different. Even though the virtual reality response times were slightly lower, the difference was not great enough to account for chance. Whatever the effect of total immersion is, it did not manifest itself in significantly faster response times for the virtual reality platform.

The finding of significant differences in response times from trial one (4.01) to trial two (2.90) confirms results of prior studies (Okagaki & Frensch, 1994, Subrahman & Greenfield, 1994). It was theorized that given a fairly extensive amount of practice on the first trial, trial one subjects would perform better on trial two. It was also expected that low spatial subjects would benefit more from the practice than would the high spatial ability subjects. It was indeed the case, as Subrahmanyam (1994) had found earlier, that low spatial subjects were able to reduce response times by a greater amount than their high spatial counterparts (1.57 seconds by the second trial compared to 0.656 seconds for the high spatial subjects). However, this difference was not statistically significant.

It seems that the lower spatial ability group is simply at a lower end of a spatial ability continuum, demonstrating lower initial levels of performance but steadily increasing with increased practice. They also have more room to expand their abilities than do those who already possess a high level of skill. This in and of itself should make us weary of making to many employment determinations based solely on an individuals current level of spatial ability.

Whereas the finding of faster response times was expected, the finding of no significant differences in accuracy (trial 1=.762, trial 2 =.77) over the two trials was unexpected. The practice effect yielded faster responses at about the same accuracy rates. It is plausible that at the higher angles of rotation, where objects are most compressed and therefore most difficult to identify, subjects make a decision and stick with it over the two trials. The accuracy remains the same but the decision is made quicker the second time around than the first time.

Attitude data did not reveal any significant differences but did indicate a generally unfavorable view of the virtual reality platform. Their strong reactions to the preference question and the difficulty question should give us a warning signal towards the indiscriminate use of virtual platforms for any training solution.

The results of the present study have implications for the design of instructional platforms as well as for future studies of spatial ability differences. Clearly, people bring differing levels of ability to any task they attempt. However, these abilities, and so called spatial skills amongst them, are not completely fixed but do respond to manipulation. To make selections for training or employment based solely on the basis of level of ability at a certain point in time might deny training to those who might greatly benefit from opportunities to improve their skills.

The results also call for caution in the design and use of virtual platforms for the delivery of instruction. Careful analysis of required levels of visual fidelity with which the instruction can be delivered must be made. These systems might encourage a certain feeling of immersion, but this will not come if they provide less fidelity or visual acuity, especially in tasks requiring identification of very small or detailed objects. Furthermore, potential trainees comfort and acceptance of this new kind of platform must also be weighed when deciding what kind of training platform to utilize.

More research is required to attempt to quantify the benefits and refine the potential of virtual reality systems. They appear to have considerable potential for improving performance on many tasks, but further research is necessary to identify its best and most cost effective applications.

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